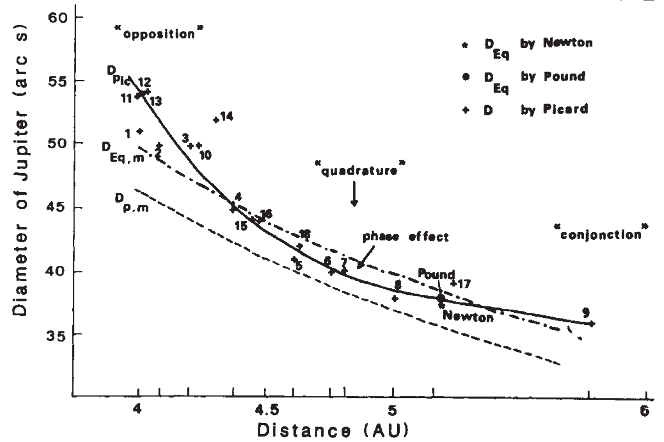
direction. If we consider the ten observations of Jupiter made by Picard that were not at opposition, the internal consistency of these observations is remarkable (see figure). The difference between Picard's diameters and the actual equatorial diameters is then reduced to −0.7 + 0.4 arc s. This difference is probably due to the phase effects, whereby the equatorial diameter of Jupiter is slightly reduced by about 0.4 arc s near quadrature because the equatorial diameter, as seen from Earth, is not totally illuminated by the Sun. The curvature noted in Picard's observations near quadrature indicates this phase effect. Had his observations been corrected for the phase effect, the discrepancy between his estimate of Jupiter's diameter and the actual diameter would be negligible.

There is, therefore, no reason to add any correction to the night measurements made by Picard. The irradiation effect is smaller for the Sun than for Jupiter, as it is partially dependent upon the focal length of the refractor. The 6-ft quadrant used for the Sun was more favourable than the 14-ft refractor used for the planets. According to Lalande[5], a systematic correction of 3–5 arc s should be applied to the seventeenth- and the eighteenth-century micrometer and transit observations if they are to be comparable with solar diameters derived from an eclipse. This correction reduces the solar diameter of Picard and La Hire to 32′6″ or 32′4″ during the deep Maunder minimum, and to 32′3″ or 32′1″ at the end of the Maunder minimum. The latter estimate is in agreement with the solar eclipse observed by Halley in 1715, also at the end of the Maunder minimum.

The correction of 3–5 arc s contains all possible sources of errors (optics, seeing, personal bias), and is quite compatible with our results. O'Dell and Van Helden have invoked a hypothetical systematic error on the transit timings. They suggest that a systematic error would remain even after smoothing out the individual fluctuation due to the quantization of time with a large number of observations. This is not possible. The accuracy of the pendulum used by Picard was better than two seconds per day, which results in an uncertainty of 0.02 arc s on the solar diameter. As discussed in our paper[1], the large error due to the quantization of time by the observer is divided by the square-root of the number of annual observations and leaves no systematic error. Our conclusions therefore remain unchallenged.

E. Ribes
Observatoire de Paris, 92195–Meudon, France

J. C. Ribes
R. Barthalot
Observatoire de Lyon, 69230–Saint Genis-Leval, France



The diameter of Jupiter observed by Picard (+) plotted against the distance between the planet and the Earth. Stars and circles refer to the equatorial diameter of Jupiter, observed by Newton and Pound, respectively, during the Maunder minimum. The modern values of the equatorial (dots) and polar (dashes) diameters of Jupiter are shown for comparison. Near quadrature, the observations made by Picard and his seventeenth-century colleagues are in good agreement with present-day esimates of the equatorial diameter. Close to opposition, the difference in Picard's observations is probably due to the irradiation effect.

O'Dell and Van Helden reply— Picard did not state which diameter of Jupiter he measured because it made no difference: first, he could barely verify that the planet is oblate but could not measure a difference between the polar and equatorial diameters; second, the differential atmospheric refraction in the case of Jupiter is negligible (0.04 arc s at an elevation of 30°), and Picard was aware of this since his refraction table did not vary much from the currently accepted one. Picard's telescopes had no clock-drives, and it was impossible to follow a planet (moving through the field at the rate of 15 arc s per second of time) smoothly enough to measure the horizontal diameter with any reasonable accuracy. The most natural way to measure a diameter was to hold the telescope firm and allow the planet to traverse the field, grazing the micrometer hairs. In the case of Jupiter, this meant measuring the polar diameter. Ribes *et al.* state that it was usual to measure a planet's horizontal diameter but offer no evidence for this statement.

Ribes *et al.* cite measurements by Newton and Pound and argue that these colleagues were also concerned with atmospheric refraction in this context. An examination of Book III, Proposition XIX of the third edition of Newton's *Principia* (1726, not 1694) reveals no mention of atmospheric refraction in this context.

More important, Newton did not measure Jupiter's diameter at all: he relied on measurements made by James Pound. Newton discussed these measurements in Book III, Phenomenon I, and it is very clear from this discussion that he was well aware of the problems posed by irradiation and micrometer errors. He based his conclusion that at mean distance Jupiter's apparent diameter is 37 arc s on Pound's timing of transits of Jupiter's satellites across the planet's disk. This method is insensitive to irradiation effects. Not quite as accurate were the micrometer measurements made by Pound with a 123-foot telescope (whose aperture ratio approached f200), by means of which apparent diameter of 39 arc s was measured. With shorter telescopes, such as those used by Picard, Newton was of the opinion that Jupiter's apparent diameter would be measured to be 41 arc s. Newton's judgment is echoed by Lalande: seventeenth-century micrometer measurements were too large by three to five arc seconds, and this is precisely our point.

In our paper[2] we relied on Auzout's report to the French Academy, which was written at about the same time as his *Manière Exacte*. It is not a preliminary report but a slightly earlier report.

Ribes *et al.* present data to try to establish a variable irradiation correction depending on illumination of the sky, so that the correction would be smaller at quadrature than at opposition. If this effect were important, the correction should be even smaller near conjunction, yet Picard's measurement no. 9 on the figure, made near conjunction, indicates a larger correction than the measurements made at quadrature. We conclude that this condition of the observations is not important.

Finally, it appears that Ribes *et al.* simply do not understand the 'personal equation' in astronomical measurements. It is a non-statistical effect that varies from observer to observer and arises from systematic early or late timing of an event.

C. R. O'Dell
A. Van Helden
Scientia, Rice University, PO Box 1892, Houston, Texas, USA

1. Ribes, E., Ribes, J. C. & Barthalot, R. *Nature* **326**, 52–55 (1987).
2. O'Dell, C. R. & Van Helden, A. *Nature* **330**, 629 (1987).
3. Picard, J. manuscripts D1, 14–16, *Archives de l'Observatoire de Paris* (1666–1682).
4. Newton, I. *Philosophiae Naturalis Principia Mathematica*, **LIII**, Phaenom. Prop. XIX, 3rd Edn (1694).
5. LaLande, J. *Astronomie*, Ed. Desainp, Paris, 2nd edn (1771).
6. Auzout, A. *Mémoires de l'Académie des Sciences (Paris)*, Tome VII, 118–130 (1729).
7. Auzout, A. *Phil. Trans. R. Soc.* **21**, 373 (1667).